



National Aeronautics and
Space Administration



Institutional Schlieren: A Production-Level Wind Tunnel Test Measurement

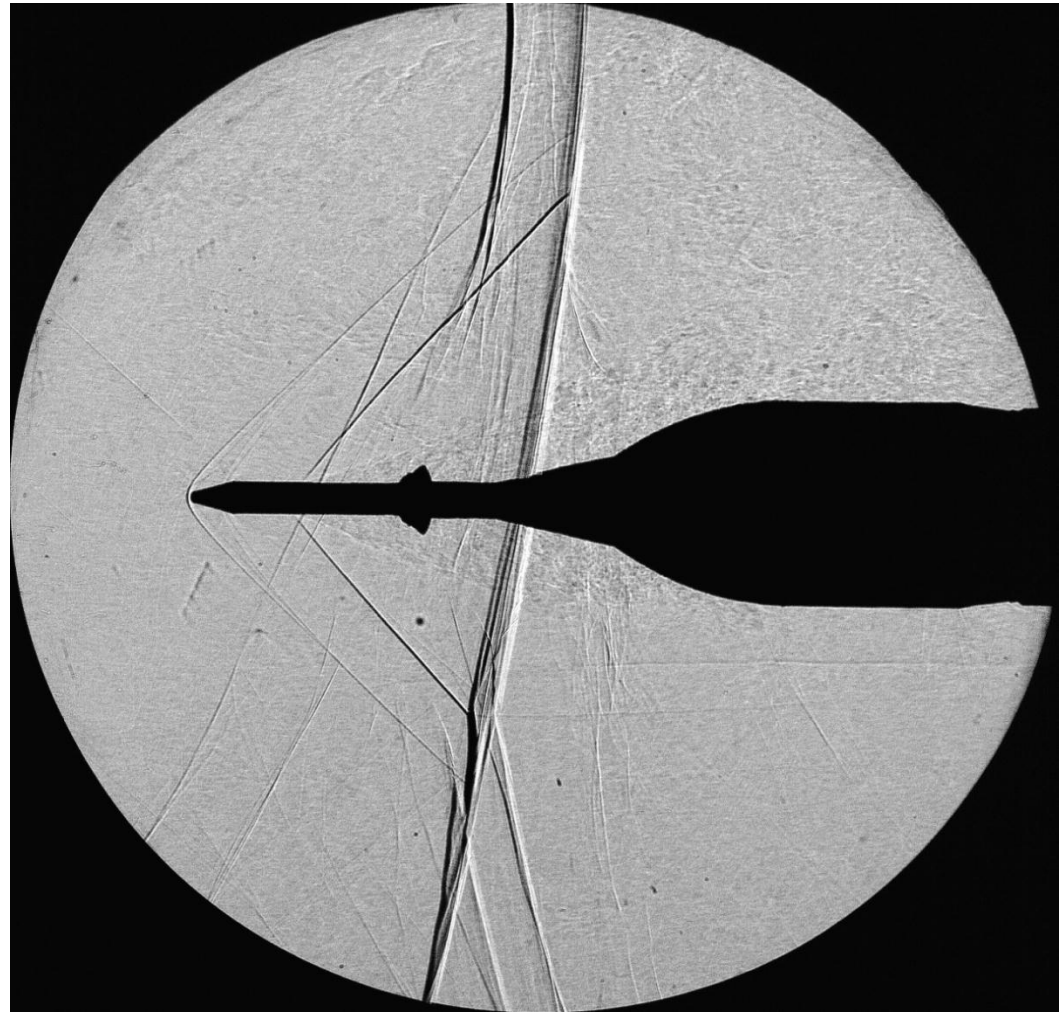
01/08/2015

Ted Garbeff
NASA Ames AOI
Theodore.J.Garbeff@nasa.gov

James T. Heineck
NASA Ames AOX
James.T.Heineck@nasa.gov

T. Kevin McDevitt
NASA Ames AOI
Kevin.McDevitt@nasa.gov

Laura Kushner
Aerospace Computing Inc.
Laura.K.Kushner@nasa.gov



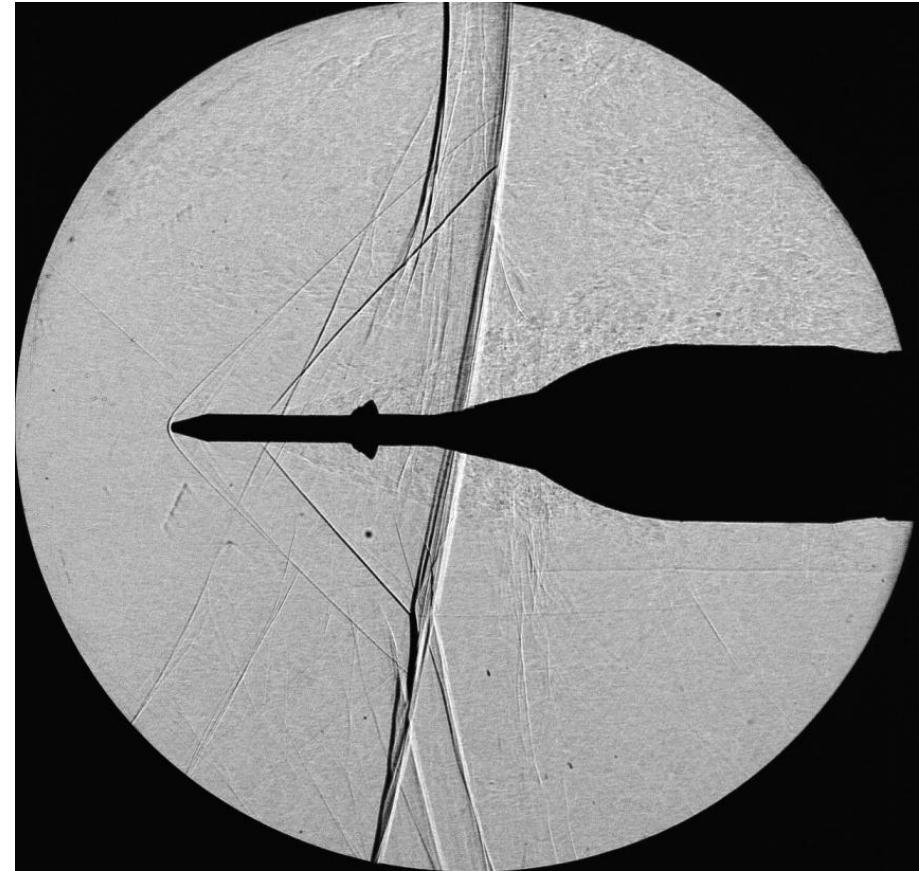


National Aeronautics and
Space Administration



Outline

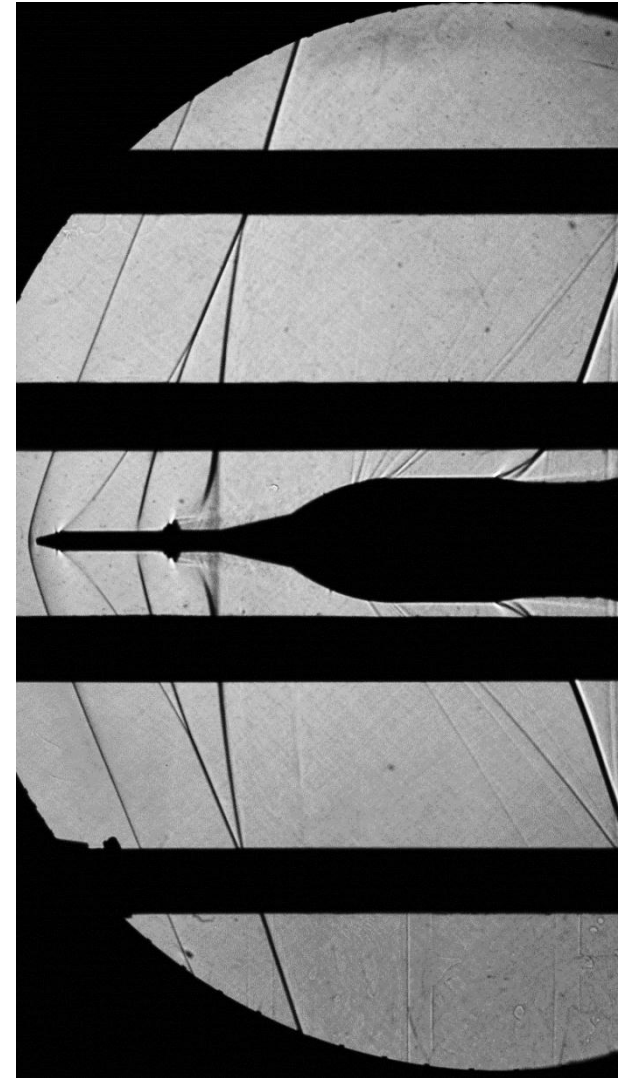
- Use of schlieren/shadowgraph at NASA Ames Unitary Plan Wind Tunnel (UPWT).
- Institutional schlieren/shadowgraph data systems modernization project.
 - Hardware selection.
 - Software methodology.
- Overview of completed data systems.
 - High-level system components.
 - Image acquisition and processing.
 - Current system capabilities.
- Future target capabilities/improvements.





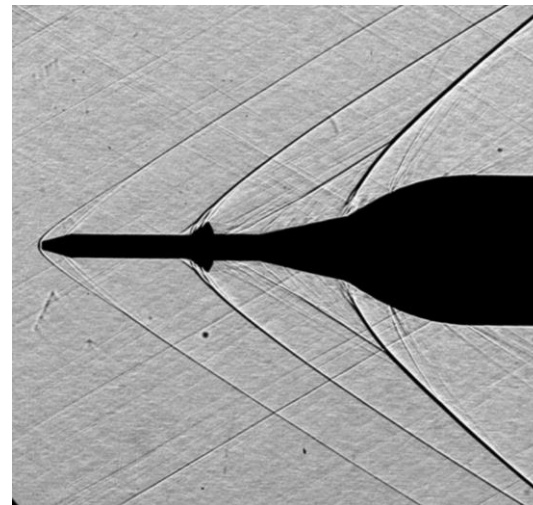
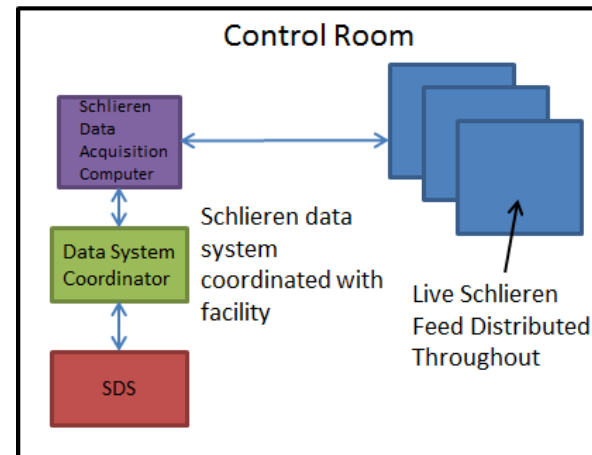
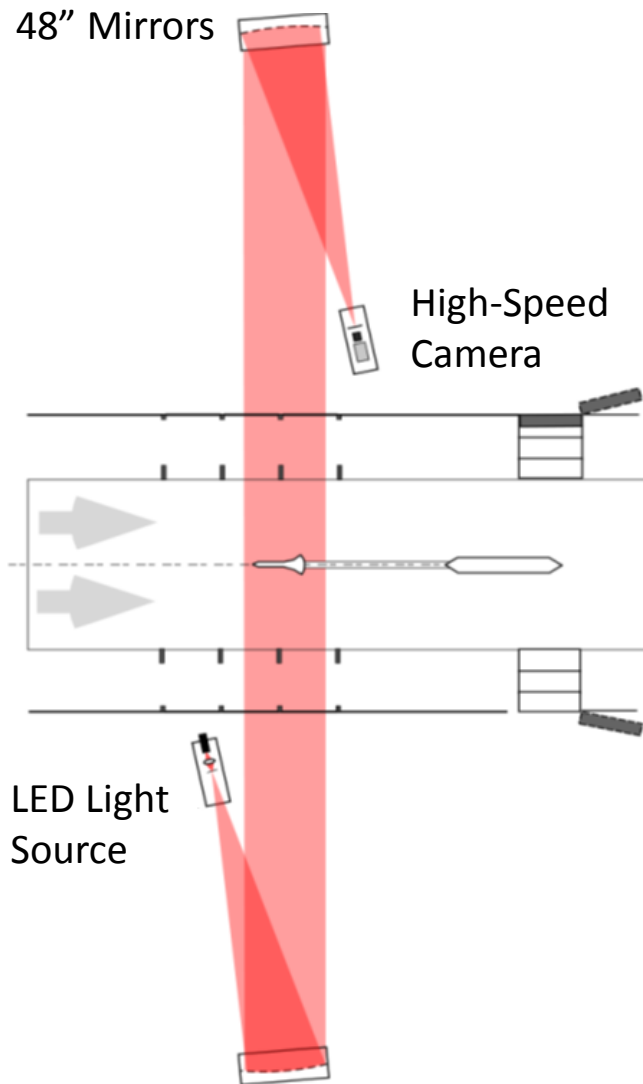
Overview of Schlieren/Shadowgraph

- Technique often deployed as a test dependent facility measurement.
- Technique used to observe phenomena that are not visible to the unaided eye. Allows observation of aerodynamic flow features:
 - Model shockwave formation and interaction.
 - Flow separation.
 - Mach wave radiation.
- Caused by density gradients created by flow phenomena. Technique exploits index of refraction changes in test section.
- Optical technique,
 - Point light source collimated on one side of test section using large concave mirror.
 - Collimated light passed through test section.
 - Light collected by a large concave mirror and imaged onto camera on other side of test section.





NASA Ames Unitary Plan Wind Tunnel Schlieren/ Shadowgraph





National Aeronautics and
Space Administration



Motivation

- Historically Ames Unitary Plan Wind Tunnel (UPWT) provided customers optical data services on a per test basis.
- These optical data services typically consist of Schlieren, Shadowgraph, infrared thermography, and pressure sensitive paint (PSP).
- Hardware/personnel furnished by Experimental Aero-Physics branch.



“Institutionalize optical data services” projects focusing on Schlieren, Shadowgraph, IR thermography, and pressure sensitive paint with the goals of:

- Purchasing state of the art, dedicated facility instruments.
- Improving data productivity by developing new data systems controls tools.
- Improving data product quality.
- Reducing data product delivery times.



Objective: Institutionalize/modernize UPWT Schlieren/Shadowgraph systems with an emphasis on test productivity and data quality.

- Purchasing/deploy dedicated hardware in both 11-by-11 and 9-by-7 foot test areas.
 - State of the art cameras and acquisition/control equipment.
 - Light sources, optics, mounts, remote controls.
- Develop improved software architecture.
 - Reduce labor intensive aspect of optical services.
 - Improve near-time delivery of data products to customers.

Requirements:

- Minimize impact to test productivity.
 - Automate data collection process.
 - Improve camera throughput.
- Capture unsteady flow field phenomena when needed.
 - Camera used must be capable of high frame rates, but of sufficient resolution.
- Improve delivery rate of data products.
 - Camera used must have fast download rates.
- Develop a group of standardized data products.
 - Pixel averaged image.
 - Low-speed video.
 - High-speed video.



Hardware Down Select Criteria

Selecting a Camera

- Frame rate versus resolution
- Sensitivity
- Stability/Reliability
- Data transfer
- Workflow
- Auxiliary outputs

Selecting a Light Source

- Power output
- Stability/Reliability
- Point size
- Configurability

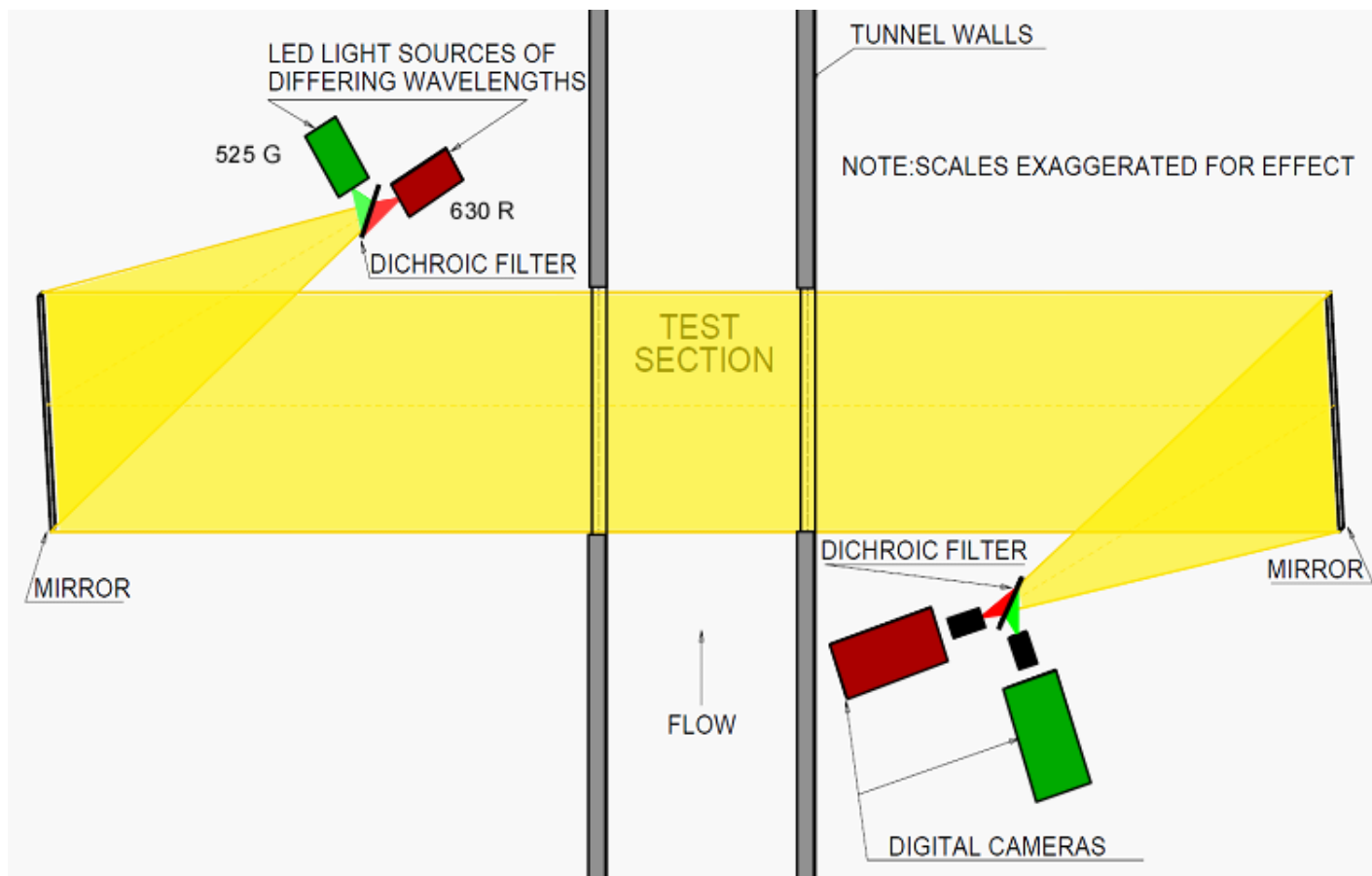
Selecting Image Acquisition/Processing

- Reliability
- Ease of use
- Redundancy
- Expandability

Testing in Production Wind
Tunnel Environment

Dual-Color Shadowgraph

- A dual-color shadowgraph configuration was used to evaluate multiple makes and models of cameras in the wind tunnel during production testing.





Cameras and Light Sources

- Evaluated several high-speed camera manufacturers in facility.
- The Vision Research Phantom v2010 best fit unique needs of Ames UPWT.
- Selected new high-powered pulsed LED light sources.

Phantom v2010



- 22,500 FPS at 1280x800 pixels.
- ISO 64,000.
- 10 Gigabit Ethernet (~350 MB/sec)
- HD-SDI Auxiliary Output

ISSI LMS-520/LMS-620



- High-powered (2-3W) pulsed LED.
- Operated continuous or pulsed.
- Green and red wavelengths.



Image Acquisition and Processing

- A single server-class, rack-mount PC for both image acquisition and processing.

Server-class SuperMicro



- Dual six-core 2.4 GHz Xeon processors
- 24 GB RAM
- 64-bit Windows 7
- LabVIEW Developers Suite 2013 SP1
- LabVIEW Vision Development Module
- 4TB Raid 1

Intel AT2 10 Gigabit Server Adapter



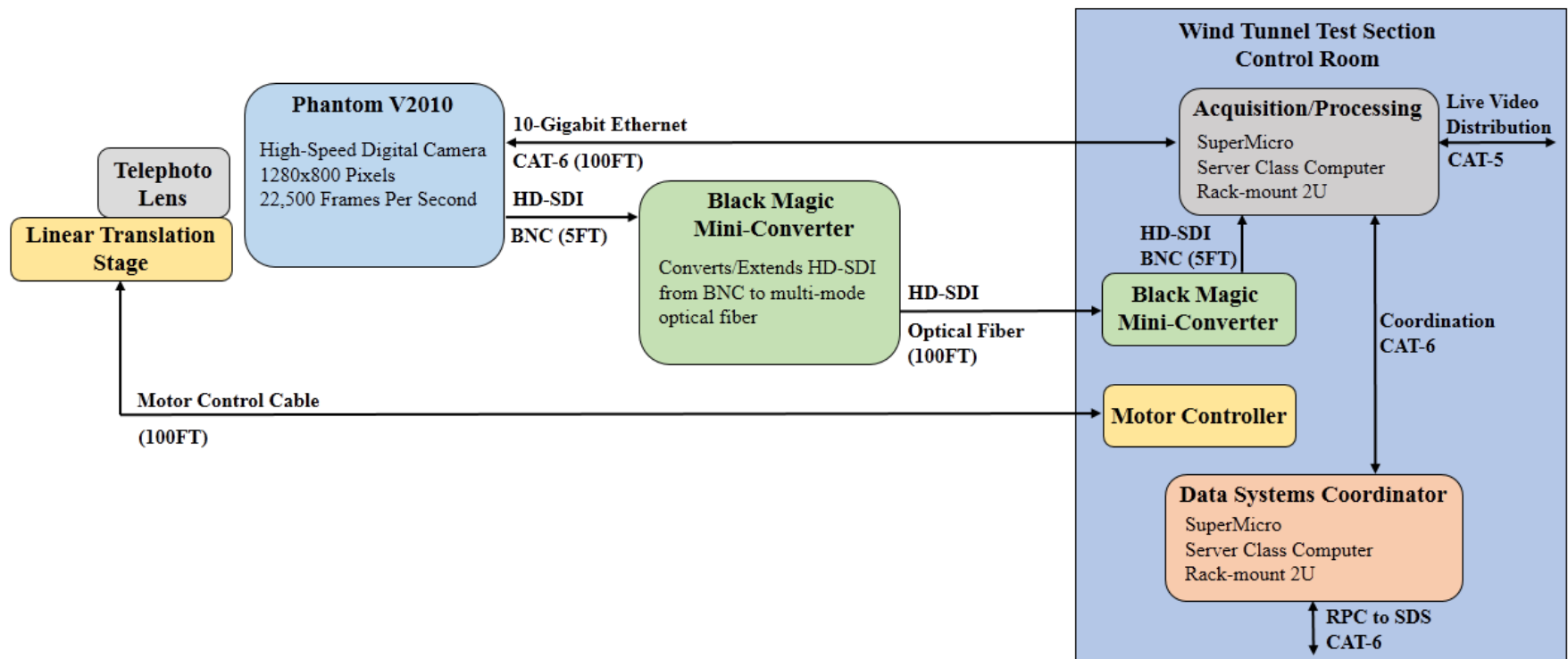
MatrixVision HD-SDI Framegrabber





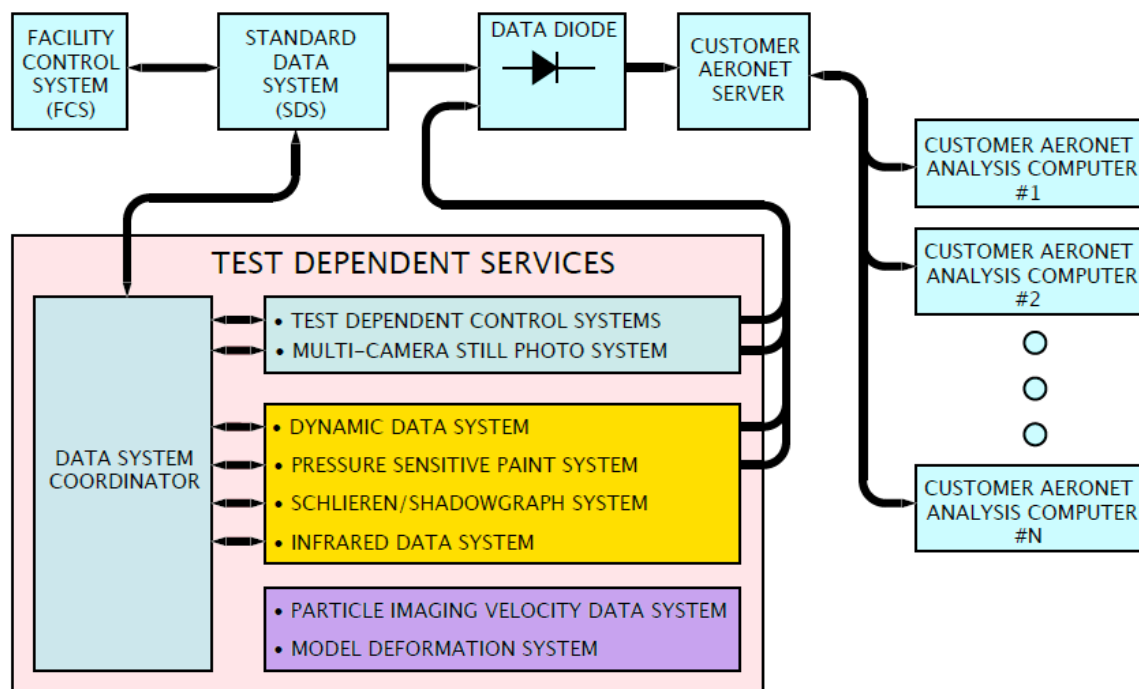
High-Level Data System Schematic

- Two complete data systems deployed in both 11-by-11 foot and 9-by-7 foot test areas.



UPWT Data Systems Architecture

- Data systems coordinator (DSC) interfaces any number of “test dependent” data services.
- Network published “shared variables” and remote procedure calls allows information flow to and from schlieren/shadowgraph data system.



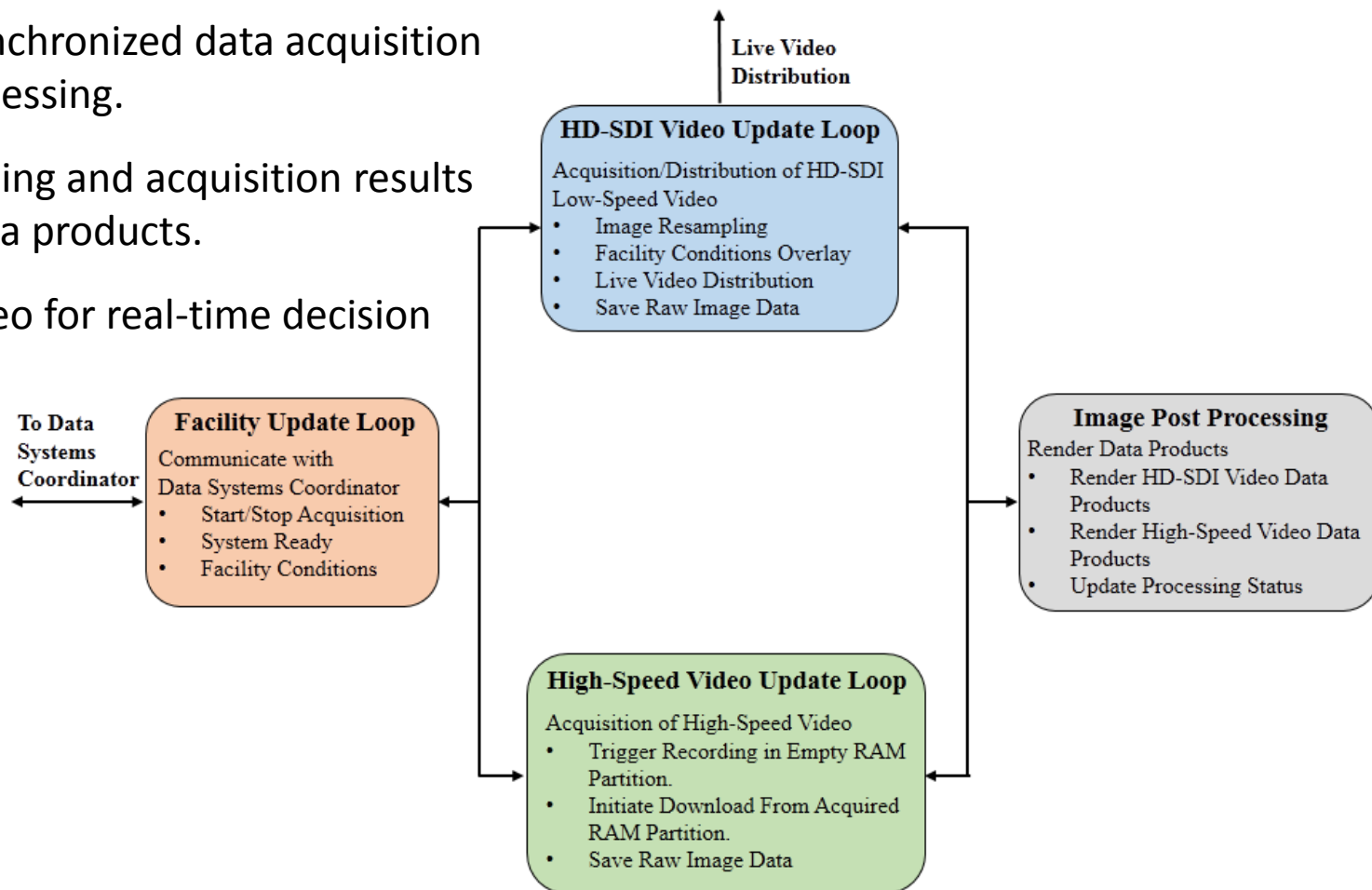
SERVICE SUPPLIED BY

- WIND TUNNEL OPS
- WIND TUNNEL OPS AND AEROPHYSICS BRANCH
- AEROPHYSICS BRANCH



Image Acquisition and Processing Architecture

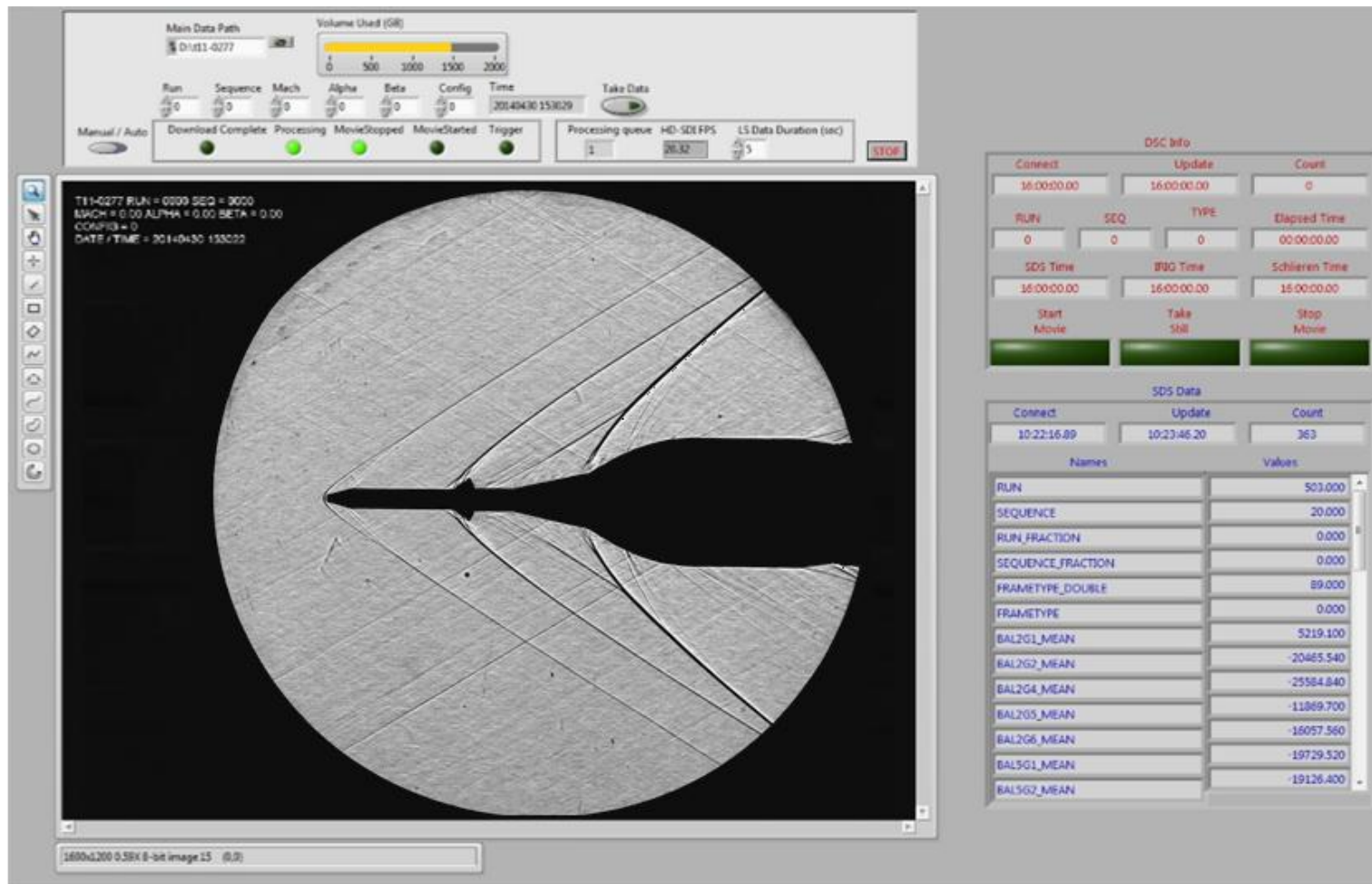
- LabVIEW based data system developed in-house.
- Automated, synchronized data acquisition and image processing.
- Parallel processing and acquisition results in real-time data products.
- Distributed video for real-time decision making.





Data System Graphical User Interface

- In-house developed camera acquisition/processing software utility.





Live Distributed Video Feed

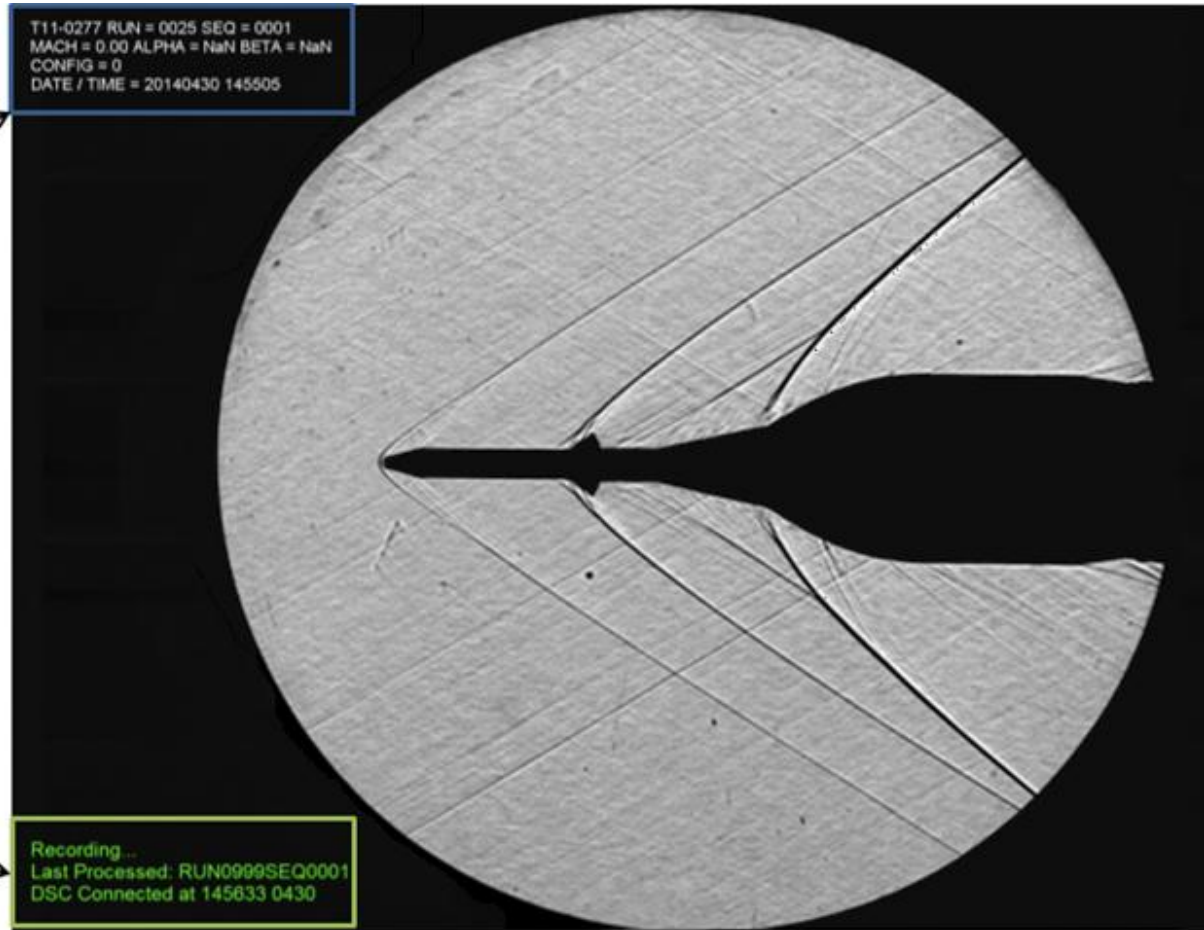
- Permanent overlay displays test conditions as communicated from the facility.
- Non-destructive overlay indicates acquisition system health and status.

Overlay of
Current Test
Conditions

T11-0277 RUN = 0025 SEQ = 0001
MACH = 0.00 ALPHA = NaN BETA = NaN
CONFIG = 0
DATE / TIME = 20140430 145505

Data System
Status Info

Recording...
Last Processed: RUN0999SEQ0001
DSC Connected at 145633 0430



Overview of Data Products

Data Products/Data Point =

- Low-Speed Video (HD-SDI), 1080p acquired up to 30 FPS
- High-Speed Video (Digital), 550 frames @ 26010 FPS
- Stills
- Averaged Still (pixel average of all stills)

All processed automatically and in parallel with acquisition.

RUN0010SEQ0001	
RUN0010SEQ0002	
RUN0010SEQ0003	
RUN0010SEQ0004	
Low-Speed Image Data	High-Speed Image Data
RUN0010SEQ0004_LowSpeed.AVI	RUN0010SEQ0004_HighSpeed.AVI
RUN0010SEQ0004_Frame1.TIFF	RUN0010SEQ0004_AVG.TIFF
.	RUN0010SEQ0004_Frame1.TIFF
.	.
.	.
.	.
.	.
.	.
.	.
.	.
.	.
.	.
.	.
.	.
RUN0010SEQ0004_Frame100.TIFF	RUN0010SEQ0004_Frame100.TIFF



Spectral Shadowgraphy

- High frame-rates make dynamic analysis possible.



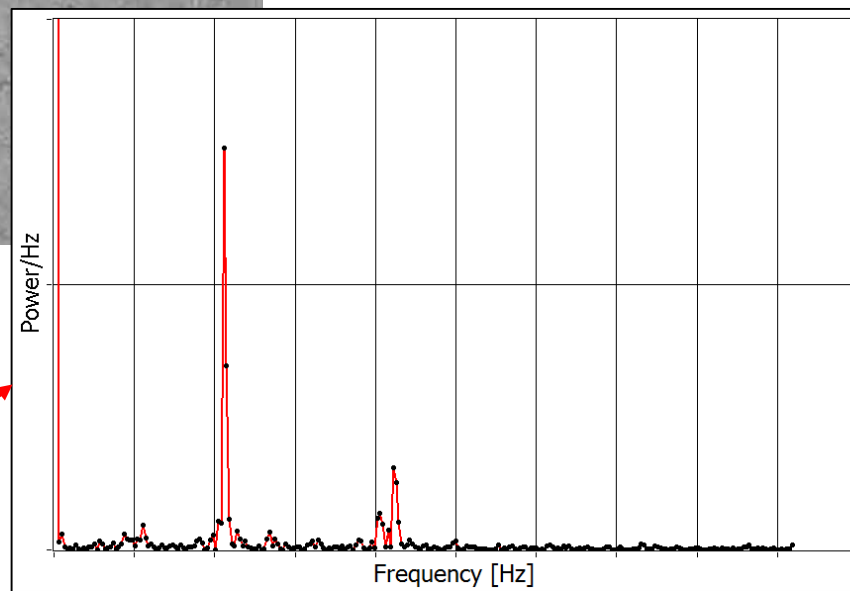
Pixel Average Time History

Region of Interest



Zoomed ROI

PSD
Computed from
image data





Future Capabilities

Dual Schlieren/Shadowgraph

- Augment dual imaging concept with addition of high-resolution, wide-field camera.

Remote Optomechanics

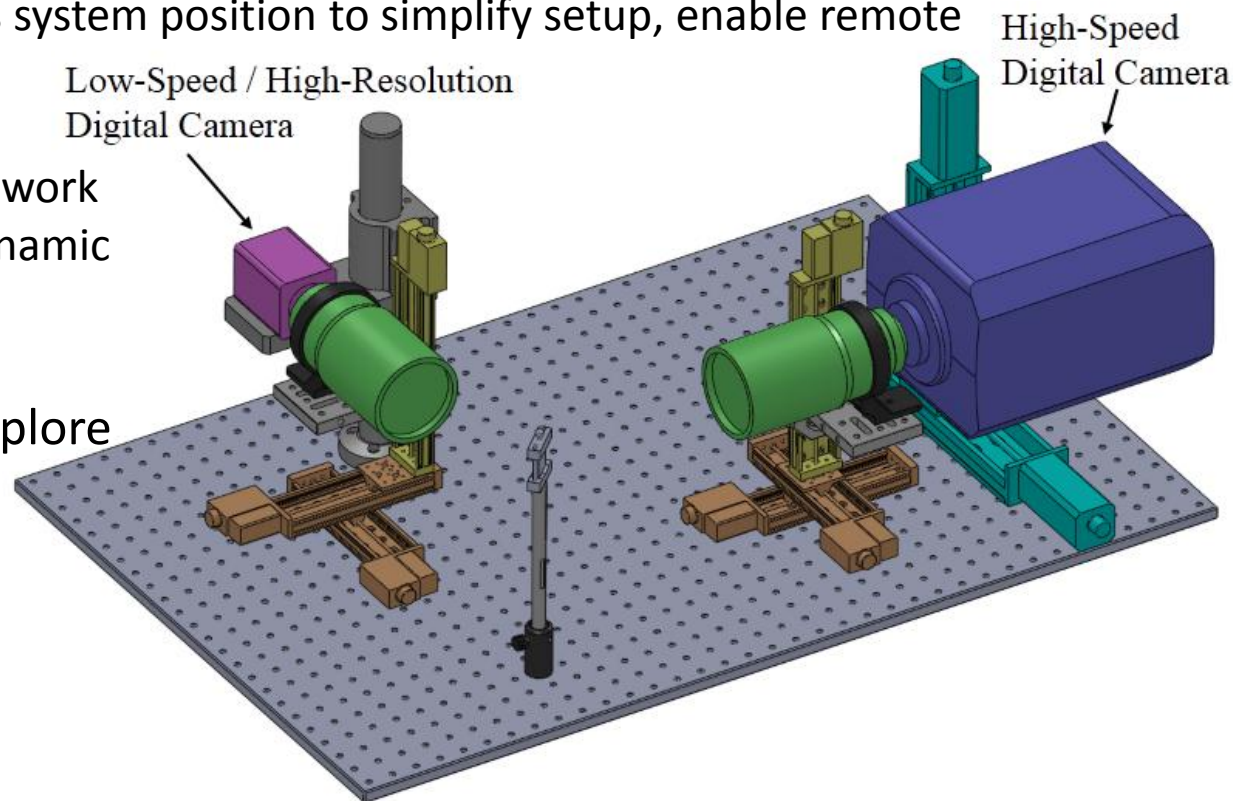
- Ability to traverse in three axes and rotate in two.
- Remote control of camera/lens system position to simplify setup, enable remote panning.

Advanced Processing

- GPU accelerated processing to work large data sets and perform dynamic analysis.

Advanced Optics

- Correct astigmatism and explore stereoscopic techniques.

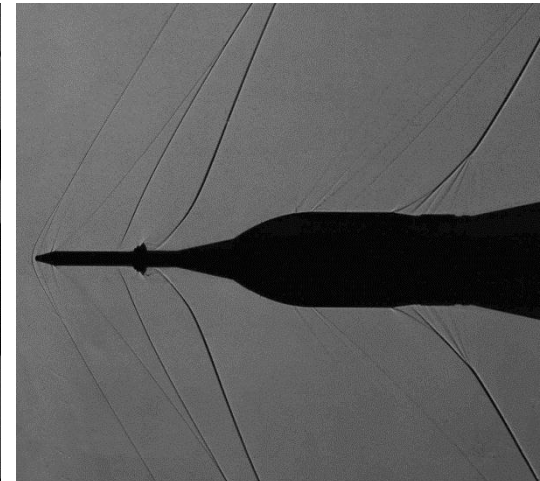
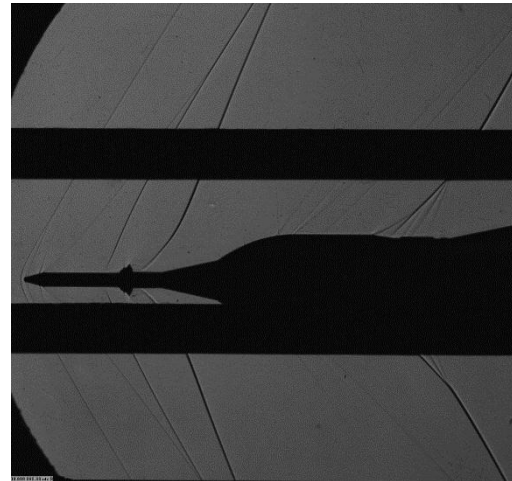
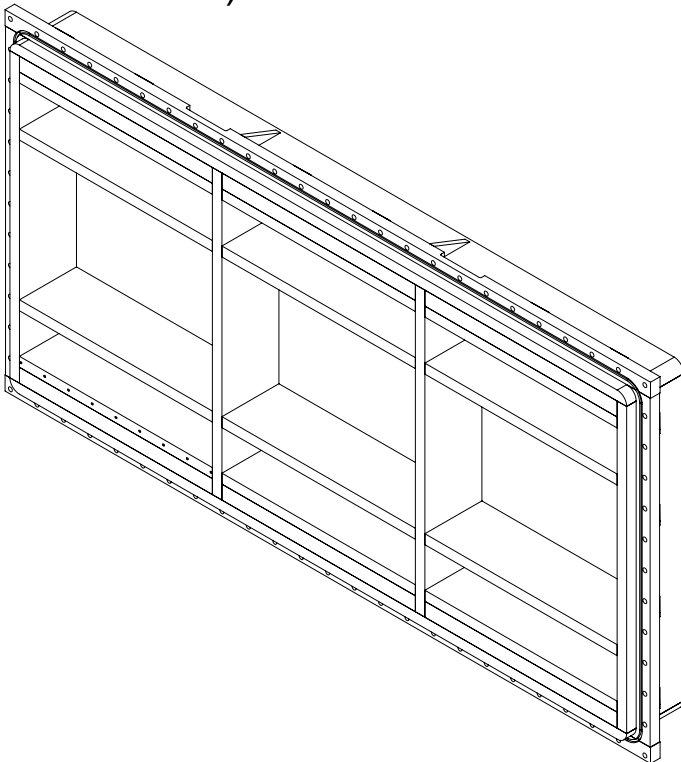




Optical Test Section of the Future

Improved viewing for Schlieren/Shadowgraph

- New larger windows to replace the 3 center rows allow for unobstructed Schlieren viewing.
- Removal of two wall slots between rows may affect tunnel calibration and test section airflow:
 - Flow measurements are being taken to quantify the effects.
 - Options for eliminating flow effects are being developed (i.e. interchangeable window section).



Resulting improved imaging from larger window

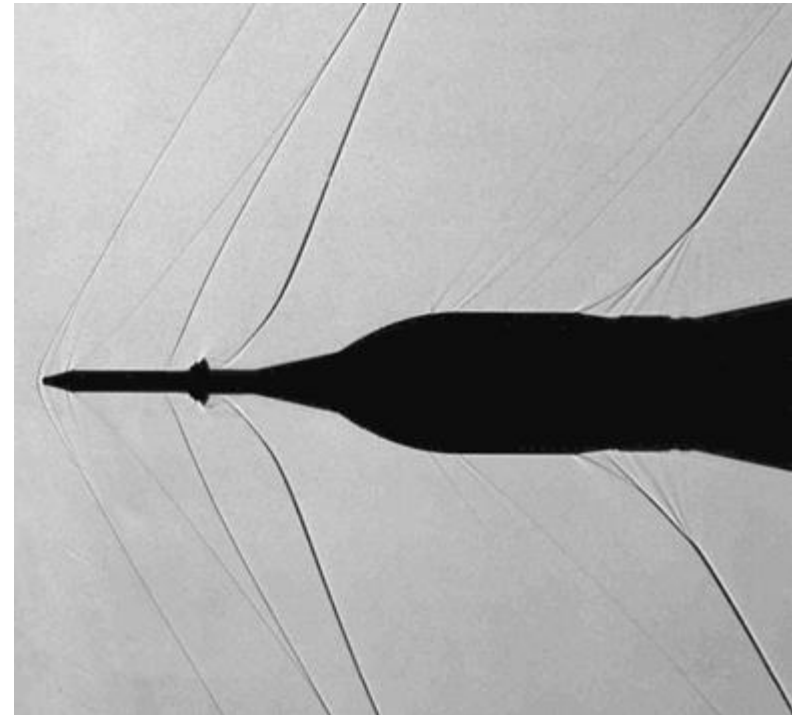
New Larger Window Concept



Conclusions

Advanced, institutional, production-level schlieren/shadowgraph systems at Ames UPWT 11-by-11 and 9-by-7 foot test sections.

- Hardware down-select:
 - High-speed digital cameras.
 - High-powered LED light sources.
 - Server-class computing for acquisition and processing.
- New software:
 - LabVIEW based acquisition and processing.
 - Data system synchronized to facility through data systems coordinator.
 - Processing done in parallel with acquisition.
 - Data products standardized and available real-time.
- New capabilities:
 - High frame-rates allow for off-body spectral analysis of flow field for correlation with on-body acoustic measurements.
- Future capabilities:
 - Leverage dual imaging and electro-mechanical actuation.
 - Advanced processing and optics.





National Aeronautics and
Space Administration



Questions?

